III. Lafayette

Clinopyroxenite, 800 grams

fresh

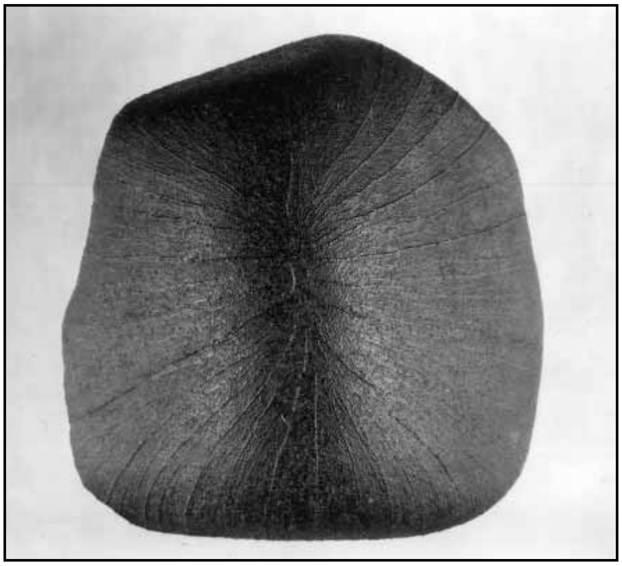

Figure III-1. *Photograph showing fine ablation features of fusion crust on Lafayette meteorite. Sample is shaped like a truncated cone. This a view of the top of the cone. Sample 4.5 centimeter across. Photograph from Field Museum Natural History, Chicago, number 62913.*

Introduction

According to Graham *et al.* (1985), *"a mass of about 800 grams was noticed by Farrington in 1931 in the geological collections in Purdue University in Lafayette Indiana."* It was first described by Nininger (1935) and Mason (1962). It may have been seen to fall by a Purdue student, but this observation can not be verified. Lafayette is similar to the Nakhla and Governador Valadares meteorites, but apparently distinct from them (Berkley *et al.,* 1980). Lafayette is a single stone with a fusion crust showing well-developed flow features from ablation in the Earth's atmosphere (figures III-1,2,3). The specimen is shaped like a rounded cone with a blunt bottom end. It was apparently oriented during entry into the Earth's atmosphere. Note that the fine ablation features seen on Lafayette have not been reported on any of the Nakhla specimens.

Karlsson *et al.* (1992) found that Lafayette contained the most extra-terrestrial water of any Martian meteorite and Treiman *et al.* (1993) found that it contained the most alteration material. Kerridge (1988), Watson *et al.* (1994) and Leshin *et al.* (1996) found that the water released during stepwise heating of Lafayette was enriched in deuterium.

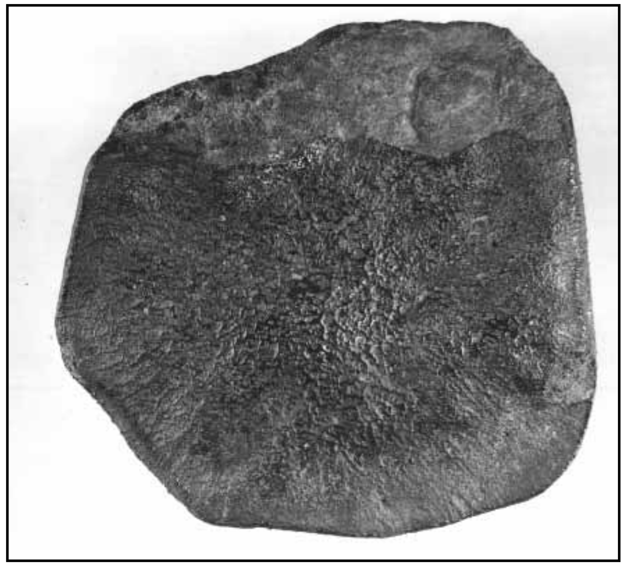

Figure III-2. *Photograph of the bottom surface of Lafayette meteorite. Photograph from Field Museum Natural History, Chicago, number 62918.*

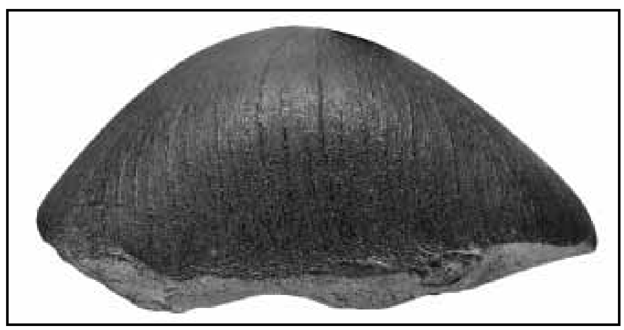

Figure III-3. *Side view of Lafayette meteorite. Photograph from Field Museum Natural History, Chicago, number 62917.*

Petrography

The petrography of the Lafayette meteorite has been described by Bunch and Reid (1975), Reid and Bunch (1975), Boctor *et al.* (1976), Berkley *et al.* (1980), Harvey and McSween (1992b) and Treiman *et al.* (1993). Treiman *et al.* (1993) describe Lafayette as a

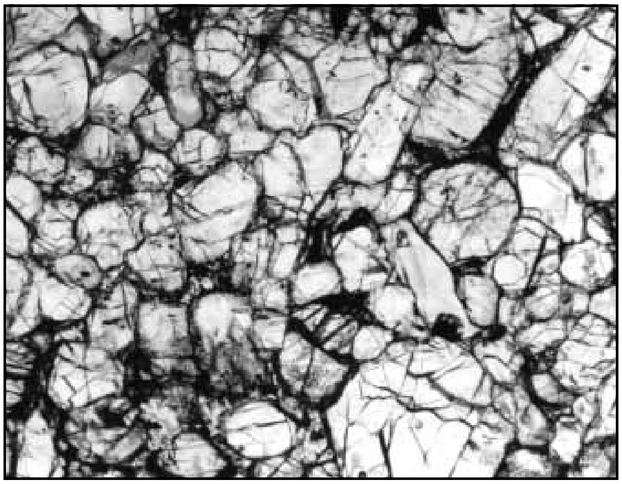

Figure III-4. Photomicrograph of thin section of Lafayette meteorite. Field of view 2.2 mm. Sample #1505-3 from the Smithsonian.

cumulate clinopyroxenite where the cumulus material is represented as subhedral augite and olivine grains (figure III-4). The elongate pyroxenes in the nakhlites are weekly aligned (Berkley *et al.*, 1980). Among the cumulus grains is intercumulus material (mesostasis) consisting of plagioclase, orthopyroxene, pigeonite, alkali feldspar, Ti-magnetite, ilmenite, pyrite, silica-glass and minor phases.

Post-magmatic hydrous alteration material is apparent in hand-specimen and thin section as rusty red-orange to black veins, staining and intergranular films (Treiman *et al.*, 1993). Olivine is the most altered, but similar staining occurs in pyroxene and throughout the sample (figure III-5).

Two pyroxene geothermometry for Lafayette indicates temperatures around 950°C, suggesting subsolidus equilibration (Harvey and McSween, 1992b). However, the Fe/Mg ratio of the olivine shows that it is out of equilibrium with the pyroxene.

Mineral Chemistry

***Olivine*:** The olivine (Fa_{65}) in Lafayette has higher Fe/Mg than that of coexisting pyroxene. A careful study of olivine zoning by Harvey and McSween (1992b) noted that olivine in Lafayette has relatively homogeneous Fe, Mg composition, indicating that it re-equilibrated with the intercumulus liquid during cooling. Smith *et al.* (1983) determined trace elements in olivine from Lafayette. They noted high Ni and Ca contents.

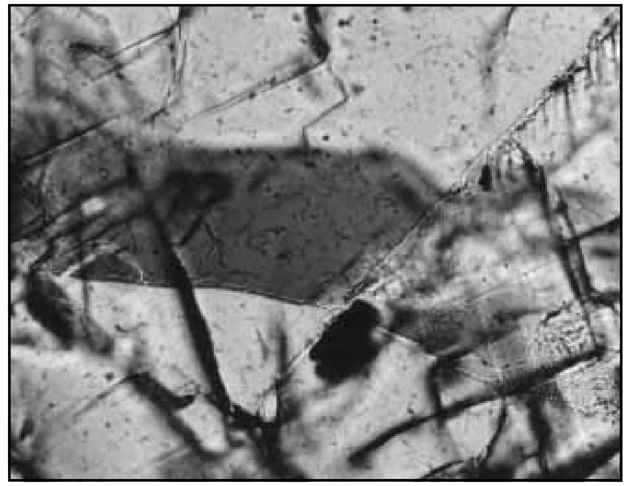

Figure III-5. Photomicrograph of thin section of Lafayette showing "iddingsite" alteration along a fracture in olivine.

***Orthopyroxene*:** Lafayette has poikilitic grains of orthopyroxene that formed from reaction of olivine with an evolving intercumulus liquid (Harvey and McSween, 1992b). The orthopyroxene is homogeneous in composition. It is a minor component, however.

***Clinopyroxene*:** The major mineral is augite ($Wo_{39}En_{39}Fs_{22}$) with little compositional zoning (Boctor *et al.*, 1976, Harvey and McSween, 1992b) (figure III-6).

***Plagioclase*:** Bunch and Reid (1975) give the composition of plagioclase as $Or_{6}Ab_{63}An_{32}$.

***K-feldspar*:** Potassium feldspar is found in the mesostasis ($Or_{76}Ab_{21}An_{2.4}$).

***Iddingsite*:** Reid and Bunch (1975) noted the fibrous habit of the alteration in Nakhla and Lafayette and reasoned that it might be *"pre-terrestrial, low temperature, alteration."* Boctor *et al.* (1976), Treiman *et al.* (1993), Romanek *et al.* (1996) studied the iddingsite in Lafayette. In particular, Treiman *et al.* showed that the smectite alteration products were indeed formed in a pre-terrestrial environment. Iddingsite is more abundant in Lafayette than in Nakhla (Karlsson *et al.*, 1992, Treiman *et al.*, 1993, Romanek *et al.*, 1996, and Bunch and Reid, 1975)(see also Oxygen Isotopes below).

Cl-apatite: Crozaz (1979) studied the U and Th distribution in Lafayette and determined the Th/U ratio in small grains (30 microns) of Cl-apatite. Bunch and

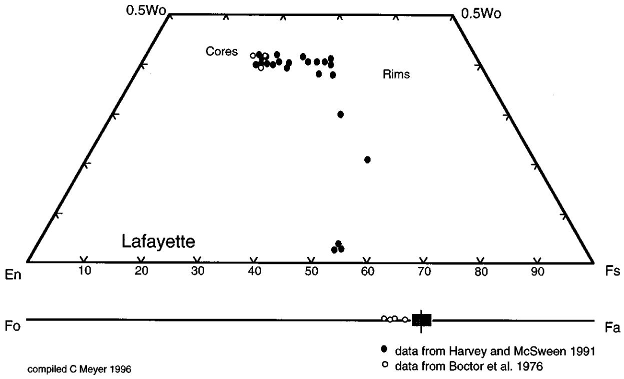

Figure III-6. *Composition diagram of pyroxenes and olivines in Lafayette. Data compiled from Harvey and McSween (1991) and Boctor et al. (1976).*

Reid (1975) reported fluor-chlorapatite (Cl=4%, F=1.6%).

***Titaniferous magnetite*:** Ti-rich magnetite in Lafayette has exsolved ilmenite lamellae (Boctor *et al.*, 1976). There is also evidence of Fe^{+3}. See also photomicrograph and analysis in Bunch and Reid (1975).

***Glass*:** Interstitial glass has been analyzed by Berkley *et al.* (1980).

***Sulfides*:** Bunch and Reid (1975) reported both troilite and "stoichiometric" pyrite. The composition of pyrite is given in Boctor *et al.* (1976). Two small grains of chalcopyrite were reported by Bunch and Reid (1975) (Cu=33%). *I remember having made this discovery in my youth!*

Whole-rock Composition

The major element composition of Lafayette is similar to Nakhla. Schmitt and Smith (1963) and Haskin *et al.* (1966) first reported REE analyses of Nakhla and Lafayette and recognized that they were generally similar in compositional patterns to terrestrial basalts (table III-1**)**. However, they noted the difference in Sc contents between these meteorites and terrestrial basalts.

Boctor *et al.* (1976) reported the analysis of the fusion crust. Gibson *et al.* (1985) determined 420 and 390 ppm S.

Karlsson *et al.* (1992) reported a total of 0.387 wt. % H_2O in Lafayette. At least some of this is extra-terrestrial weathering, as evidenced by the isotopic

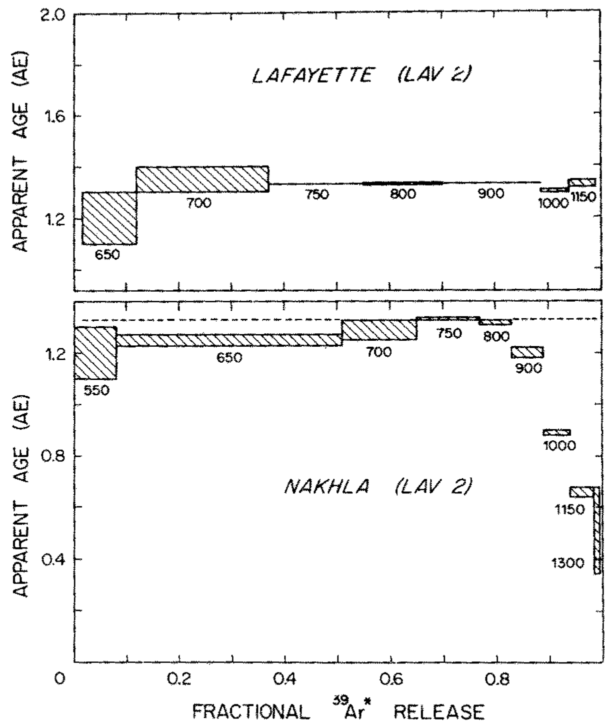

Figure 7. *Argon plateau diagram for Lafayette and Nakhla meteorites from Podesek (1973). This is a copy of figure 3 in EPSL* ***19****, 142.*

ratios. Watson *et al.* (1994) also found high water content (0.38 wt. %) for Nakhla.

Lindstrom *et al.* (1996) have analyzed the "iddingsite" for trace elements.

Radiogenic Isotopes

Using ^{4}He and ^{40}Ar, Ganapathy and Anders (1969) calculated "gas retention ages" of 0.83 Ga and 1.1 ± 0.3 Ga respectively for Lafayette. Podosek (1973) and Podosek and Huneke (1973) determined the age of Lafayette by the $^{39}Ar/^{40}Ar$ plateau technique (1.33 ± 0.03 Ga), but were hesitant to conclude that this was the crystallization age (figure III-7).

Cosmogenic Isotopes and Exposure Ages

Using ^{3}He, ^{21}Ne and ^{38}Ar, Ganapathy and Anders (1969) calculated an average cosmic-ray exposure age of 9.8 Ma for Lafayette. Podosek (1973) determined 6.5 Ma as the cosmic-ray exposure, but Bogard *et al.* (1984b) calculated ~11 Ma cosmic-ray exposure age of Lafayette.

On the basis of similar Xe isotopic compositions, Rowe *et al.* (1966) first suggested that Lafayette and Nakhla are one and the same meteorite. They noted that both Nakhla and Lafayette lacked detectable decay products

Table III-1. Chemical analyses of Lafayette.

	Schmitt 63	**Haskin 66**	**Laul 72**	**Schmitt 72**	**Boctor76**	**Podosek 73**	**Treiman 86**	**Nichipororuk**
weight				*889 mg*	*fusion crust*			
SiO_2 %					46.9 (c)			
TiO_2					0.33 (c)			
Al_2O_3					1.55 (c)			
FeO				23.03 (b)	22.7 (c)			
MnO				0.5 (b)	0.79 (c)			0.39 (e)
CaO					13.4 (c)	14.13		9.08 (e)
MgO					12.9 (c)			
Na_2O				0.43 (b)	0.36 (c)			
K_2O	0.12 (b)				0.09 (c)	0.113		
P_2O_3								
sum								
Li ppm								
C								
F								
S								
Cl						65		
Sc	77.6 (b)	54 (b)		48 (b)				
V								
Cr				1720 (b)				
Co				44 (b)				37 (d)
Ni							94 (a)	106 (d)
Cu				12 (b)				
Zn			71 (a)				72 (a)	
Ga								
Ge							2.48 (a)	
As								
Se			0.088 (a)				0.05 (a)	
Br							0.17 (a)	
Rb			2.4 (a)				3.25 (a)	
Sr								
Y	4.4 (b)	3.2 (b)						
Zr								
Nb								
Mo								
Pd ppb							<1.7 (a)	
Ag ppb			58 (a)					
Cd ppb			92 (a)				98 (a)	
In ppb			20.3 (a)				20.1 (a)	
Sb ppb							103 (a)	
Te ppb							<5.2 (a)	
I ppm								
Cs ppm			0.288 (a)				0.353 (a)	
Ba								
La	1.76 (b)	1.8 (b)						
Ce	5.48 (b)	5.5 (b)					4.21 (a)	
Pr	0.8 (b)	0.8 (b)						
Nd	3.35 (b)	3.4 (b)					3.12 (a)	
Sm	0.85 (b)	0.85 (b)						
Eu	0.24 (b)	0.24 (b)					0.188 (a)	
Gd	0.92 (b)	0.92 (b)						
Tb	0.12 (b)	0.12 (b)					0.104 (a)	
Dy	0.89 (b)	0.89 (b)						
Ho	0.146 (b)	0.146 (b)						
Er	0.4 (b)	0.4 (b)						
Tm	0.057 (b)	0.047 (b)						
Yb	0.36 (b)	0.22 (b)					0.307 (a)	
Lu	0.051 (b)	0.044 (b)					0.055 (a)	
Hf								
Ta								
W								
Re ppb							0.028 (a)	
Os ppb							<.6 (a)	
Ir ppb			0.13 (a)				0.052 (a)	
Au ppb			21 (a)				66.2 (a)	
Tl ppb			7.2 (a)				6.81 (a)	
Bi ppb			5.64 (a)				5 (a)	
Th ppm								
U ppm							0.044 (a)	

technique: (a) RNAA, (b) INAA, (c) EMPA fusion crust , (d) emission spec., (e) XRF

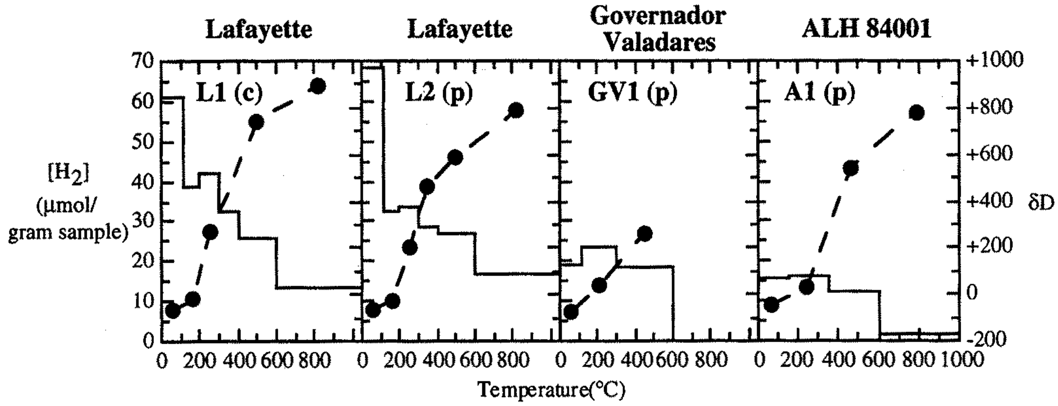

Figure III-8. *Isotopic composition of hydrogen in Lafayette meteorite from Leshin et al. (1996). This is a copy of figure 2 in GCA* ***60****, 2640. Note that water is still coming off in high temperature steps.*

of ^{244}Pu, but they observed excesses of ^{129}Xe which they inferred came from extinct ^{129}I (see Hohenberg thesis, Podosek discussion). *The excess* ^{129}Xe *is now generally interpreted as Mars atmosphere*.

Other Isotopes

Taylor *et al.* (1965) originally reported the oxygen isotopic composition of pyroxenes from Lafayette and noted the difference from other achondrites. Clayton and Mayeda (1983, 1996) reported the oxygen isotopes for Lafayette and revised the data of Clayton *et al.* (1976). Karlsson *et al.* (1992) found that the oxygen isotopes in water released from Lafayette was enriched in ^{17}O, indicating that the past hydrosphere on Mars was from a different reservoir than the lithosphere. Clayton (1993a) reported the ^{18}O/^{16}O composition of olivine and pyroxene from Lafayette and calculated the equilibrium temperature. Romanek *et al*. (1996 a,b) reported additional oxygen isotope data for various minerals including iddingsite which was found to contain δ^{18}O = +14 ‰.

Kerridge (1988), Watson *et al.* (1994) and Leshin *et al*. (1996) found that deuterium was greatly enriched in Lafayette (figure III-8).

Molini-Velsko *et al.* (1986) reported the isotopic composition of Si and found that it was normal.

The carbon and nitrogen content and isotopic composition has been reported by Wright *et al.* (1992). Kerridge (1988) also determined the isotopic composition of carbon.

Extra-terrestrial Weathering

Treiman *et al.* (1993) showed conclusively that the hydrous alteration in the cracks of Lafayette preceded the formation of the fusion crust, thus the alteration is pre-terrestrial (see also the discussion in Nakhla). Lindstrom *et al.* (1996) found that the weathering products in Lafayette were enriched in Hg, Br and alkali elements, however, the sample used in this study may have been contaminated while it was in the Museum.

Processing

Lafayette *"... had not lain on the Earth for very long time before it was picked up and protected against abuses of a mechanical nature"* (Nininger, 1935). Originally the whole specimen was curated at Purdue. The main mass is now in the Smithsonian Institution in Washington, after the Field Museum (Chicago) obtained excellent photos of the fine ablation features on the conical surface. The Field Museum retained a large piece (table I-3).